CLAIMS

1. A microvalve comprising:

a first layer, a second layer defining a flow area, and a third layer, the second layer disposed between the first layer and the third layer,

the first layer defines a first port therethrough and at least one of the first layer and the third layer defines a second port therethrough to permit fluid flow from the first port to the second port through the flow area defined in the second layer,

a first member defined by the second layer;

a displaceable structure attached to the first member and including a first end and a second end; and

a first actuator defined by the second layer and operatively coupled to the displaceable structure to displace the second end of the displaceable structure in a plane parallel to the second layer between an open state and a closed state relative to one of the first and second ports.

2. The microvalve of claim 1 further including:

a second member defined by the second layer and attached to the displaceable structure; and

a second actuator defined by the second layer and operatively coupled to the displaceable structure through the second member.

3. The microvalve of claim 2 wherein the first actuator is operatively coupled to the displaceable structure through the first member.

4. The microvalve of claim 3 further including first electrical contacts formed through the third layer and coupled to the first actuator to provide a first electrical control signal thereto and second electrical contacts formed through the third layer and coupled to the second actuator for providing a second electrical control signal to the second actuator.

5. The microvalve of claim 4:

wherein the first actuator thermally expands in response to the first electrical control signal; and

wherein the second layer includes an electrical isolation structure which electrically isolates portions of the second layer so as to allow the first electrical control signal to pass only through the first actuator.

6. The microvalve of claim 5 wherein the first actuator includes one or more extensible ribs each having a proximal end and a distal end, the proximal end of each of the plurality of extensible ribs protruding from the second layer and the distal end of each of the plurality of extensible ribs coupled to the first member.

7. The microvalve of claim 6, wherein the first member comprises a shaft extending generally perpendicularly relative to the displaceable structure.

8. The microvalve of claim 7 wherein each of the one or more extensible ribs protrudes from the first member at an angle relative to the first member, each of the one or more extensible ribs being adapted to urge the first member toward the first end of the displaceable structure upon thermal expansion of the one or more extensible ribs.

9. The microvalve of claim 8, wherein each of the one or more extensible ribs is at an angle of approximately 1-30° relative to a perpendicular of the shaft.

10. The microvalve of claim 6 wherein:

the first member and second member each include a proximal end and a distal end;

the displaceable structure includes a first end and a second end; and

the distal end of the first member and the distal end of the second member are integrally secured to the displaceable structure at respective locations closer to the first end of the displaceable structure than to the second end thereof.

11. The microvalve of claim 10 wherein the first and second members are secured on opposed sides of the displaceable structure.

12. The microvalve of claim 11 wherein the first member and the second member are secured to the displaceable structure at locations that are offset from each other along a length of the displaceable structure.

13. The microvalve of claim 12 wherein the first and second members are secured on the same side of the displaceable structure.

14. The microvalve of claim 7 wherein the first actuator and the first contacts are vertically aligned.

15. The microvalve of claim 14 wherein the second layer includes single-crystal silicon.

16. The microvalve of claim 15 wherein the first and second members and the displaceable structure include single-crystal silicon.

17. The microvalve of claim 16 wherein the first actuator includes single-crystal silicon.

18. The microvalve of claim 1 wherein the second end of the displaceable structure includes an extension which at least partially surrounds the second port, the extension further defining the flow area defined by the second layer.

19. The microvalve of claim 18, wherein the extension is U-shaped.

20. The microvalve of claim 18 wherein the extension completely surrounds the second port.

21. The microvalve of claim 18 further including a flow director fixed to one of either the first layer or the third layer and adjacent to the second port.

22. The microvalve of claim 21 wherein the flow director is a substantially U-shaped.

23. The microvalve of claim 22 wherein the flow director includes a curved surface.

24. The microvalve of claim 1 wherein the second end of the displaceable structure includes an extension which surrounds the first port.

25. The microvalve of claim 1 wherein the first actuator includes at least one sensor for sensing actuation of the first actuator.

26. The microvalve of claim 1 including a sensor operatively coupled to the displaceable structure and for sensing displacement thereof.

27. The microvalve of claim 26 wherein the sensor is attached to the first member.

28. The microvalve of claim 26 wherein the sensor is a peizoresistive device.

29. The microvalve of claim 1 wherein the second end of the displaceable structure includes an extension which surrounds only the first port, the extension further defining the flow area defined by the second layer.

30. The microvalve of claim 1 wherein a width of the displaceable structure increases from the first end to the second end thereof.

31. The microvalve of claim 1 wherein a width of the displaceable structure is smaller at a second end thereof that at a first end thereof.

32. The microvalve of claim 1 wherein a width of the displaceable structure decreases from the first end to the second end thereof.

33. The microvalve of claim 32, wherein the first actuator is disposed outside of the flow area.

34. The microvalve of claim 1, wherein the first actuator is formed by deep reactive ion etching.

35. The microvalve of claim 34, wherein the displaceable structure is formed by deep reactive ion etching.

36. The microvalve of claim 1 wherein the second layer includes highly doped single-crystal silicon.

37. The microvalve of claim 1, wherein the third layer further defines a third port disposed substantially opposite to the first port of the first layer.

38. The microvalve of claim 1, further comprising a fourth layer, the third layer disposed between the second and fourth layers, wherein the first, second and third layers define a channel therethrough, the channel being enclosed in part by the fourth layer and having an opening in each of the first and the third layers for delivery of fluid from the first layer opening to the third layer opening and into the flow area, the third layer opening being substantially coaxially disposed relative to the first port of the first layer.

39. The microvalve of claim 1 further including a third port formed in either one of the first and the third layers, the first port and the third port being alternate inlet ports.

40. The microvalve of claim 39 wherein the displaceable structure includes a substantially U-shaped extension at the second end thereof, the U-shaped extension to move between an open state and a closed state with respect to the first port and the third port.

41. The microvalve of claim 40 further including:

a second displaceable structure having a first end and a second end; and

a second actuator coupled the second displaceable structure to move the second end thereof between an open state and a closed state relative to the third port.

42. The microvalve of claim 1 wherein the displaceable structure has a length and wherein the actuator is secured to the displaceable structure at a location along the length of the displaceable structure.

43. The microvalve of claim 1 wherein a pressure sensor in located in the first layer to measure the pressure difference between the inlet port and the outlet port.

44. A microvalve comprising:

a first layer, a second layer and a third layer, the second layer disposed between the first and third layers,

the first layer defines a first port therethrough and at least one of the first and third layers defines a second port therethrough to permit fluid flow from the first port to the second port through a flow area defined in the second layer,

a first member suspended within the cavity region and including a proximal end and a distal end, the proximal end of the first member integrally secured to the second layer;

a second member suspended within the cavity region and including a proximal end and a distal end, the proximal end of the second member integrally secured to the second layer;

a displaceable structure suspended within the cavity region and including a first end and a second end, the displaceable structure integrally secured to the distal end of the first suspended member and to the distal end of the second suspended member; and

a first actuator unitarily formed in the second layer and operatively coupled to the first suspended member so as to displace the second end of the displaceable structure in a plane defined by the second layer and at a position between an open state and a closed state relative to one of the first and second ports; and

first electrical contacts formed through the third layer and coupled to the first actuator to provide a first electrical control signal thereto.

45. The microvalve of claim 44 further including a second actuator defined by the second layer and operatively coupled to the displaceable structure through the second member.

46. The microvalve of claim 45 wherein the first actuator is operatively coupled to the displaceable structure through the first member.

47. The microvalve of claim 46 wherein the first actuator and the second actuator each includes a plurality of extensible ribs each having a proximal end and a distal end, the proximal end of each of the plurality of extensible ribs protruding from the second layer and the distal end of each of the plurality of extensible ribs coupled to either the first member or the second member.

48. The microvalve of claim 44 wherein the first and second members are secured on opposed sides of the displaceable structure.

49. The microvalve of claim 48 wherein the first member and the second member are secured to the displaceable structure at locations that are offset from each other along a length of the displaceable structure.

50. The microvalve of claim 44 wherein the first and second members are secured on a same side of the displaceable structure.

51. The microvalve of claim 44 wherein the second end of the displaceable structure includes an extension which at least partially surrounds the second port, the extension further defining the flow area defined by the second layer.

52. The microvalve of claim 51, wherein the extension is U-shaped.

53. The microvalve of claim 51 wherein the extension completely surrounds the second port.

54. The microvalve of claim 51 further including a flow director fixed to one of either the first layer or the third layer and adjacent to the second port.

55. The microvalve of claim 54 wherein the flow director is a substantially U-shaped.

56. The microvalve of claim 54 wherein the flow director includes a curved surface.

57. The microvalve of claim 44 wherein the second end of the displaceable structure includes an extension which at least partially surrounds the first port.

58. The microvalve of claim 44 wherein a width of the displaceable structure increases from the first end to the second end thereof.

59. The microvalve of claim 58 wherein the width of the displaceable structure
is greater at the first end thereof than the second end thereof.

60. The microvalve of claim 44, wherein the first actuator is formed by deep reactive ion etching.

61. The microvalve of claim 60, wherein the displaceable structure is formed by deep reactive ion etching.

62. The microvalve of claim 44 wherein the second layer includes highly doped single-crystal silicon.

63. The microvalve of claim 44 wherein the third layer further defines a third port disposed substantially opposite to the first port of the first layer.

64. The microvalve of claim 44 further comprising a fourth layer, the third layer disposed between the second and fourth layers, wherein the first, second and third layers define a channel therethrough, the channel being enclosed in part by the fourth layer and having an opening in each of the first and the third layers for delivery of fluid from the first layer opening to the third layer opening and into the flow area, the third layer opening being substantially coaxially disposed relative to the first port of the first layer.

65. The microvalve of claim 44 further including a third port formed in either one of the first and the third layers, the first port and the third port being alternate inlet ports.

66. The microvalve of claim 65 wherein the displaceable structure includes a substantially U-shaped extension at the second end thereof, the U-shaped extension to move between an open state and a closed state with respect to the first port and the third port.

67. The microvalve of claim 65 further including:

a second displaceable structure having a first end and a second end; and

a second actuator coupled the second displaceable structure to move the second end thereof between an open state and a closed state relative to the third port.

68. A microvalve, comprising:

a first layer, a second layer defining a flow area, and a third layer, the second layer disposed between the first layer and the third layer,

the first layer defining a first port therethrough and at least one of the first and the third layers defining a second port therethrough to permit fluid flow from the first port to the second port through a flow area defined by the second layer,

the second layer defines a displaceable structure and at least one actuator disposed relative to a first end of the displaceable structure to move the displaceable structure in a plane parallel to the second layer, the displaceable structure movable to place a second end portion thereof at a position between an open and a closed position relative to one of the first and the second ports; and

an extension at the second end of the displaceable structure which at least partially surrounds the second port, the extension further defining the flow area defined by the second layer.

69. The microvalve of claim 68, wherein the extension is U-shaped.

70. The microvalve of claim 68 wherein the extension completely surrounds the second port.

71. The microvalve of claim 68 further including a flow director fixed to one of either the first layer or the third layer and adjacent to the second port.

72. The microvalve of claim 68 further including a flow director fixed to one of either the first layer or the third layer and adjacent to the second port.

73. The microvalve of claim 72 wherein the flow director is a substantially U-shaped.

74. The microvalve of claim 72 wherein the flow director includes a curved surface.

75. The microvalve of claim 68 further including a third port formed in either one of the first and the third layers, the first port and the third port being alternate inlet ports.

76. The microvalve of claim 75 wherein the extension is substantially U-shaped and moves between an open state and a closed state with respect to the first port and the third port.

77. A microvalve comprising:

a first layer, a second layer defining a flow area, and a third layer, the second layer disposed between the first layer and the third layer,

the first layer defines a first port therethrough and at least one of the first layer and the third layer defines a second port therethrough to permit fluid flow from the first port to the second port through the flow area defined in the second layer;

a first actuator and a second actuator each defined by the second layer and each expandable in response to application of an electrical signal; and

a displaceable structure including a first end and a second end, the displaceable structure coupled to the first actuator closer to the first end than to the second end and coupled to the second actuator closer to the second end than the first end to move the displaceable structure between an open state and a closed state relative to one of the first and second ports.

78. A microvalve comprising:

a first layer, a second layer defining a flow area, and a third layer, the second layer disposed between the first layer and the third layer,

the first layer defining a first port therethrough and at least one of the first layer and the third layer defining a second port therethrough to permit fluid flow from the first port to the second port through the flow area defined by the second layer,

at least a first actuator defined by the second layer and including a first extendable arm and a second extendable arm each extendable in response to an applied signal, the first extendable arm having a greater cross-sectional area than the second extendable arm such that the second extendable arm extends a relatively greater amount than the first extendable arm in response to a given applied signal; and

a displaceable structure having a first end and a second end and disposed relative to the first actuator to move the second end of the displaceable structure between an open state and a closed state relative to one of the first and the second ports.

79. The microvalve of claim 78 further including:

a second actuator defined by the second layer and including a first extendable arm and a second extendable arm each extendable in response to an applied signal, the first extendable arm having a greater cross-sectional area than the second extendable arm such that the second extendable arm extends a relatively greater amount than the first extendable arm in response to a given applied signal, the second actuator disposed relative to the displaceable structure to move the second end of the displaceable structure between an open state and a closed state relative to one of the first and the second ports.

80. A microvalve, comprising:

a first layer, a second layer defining a flow area, and a third layer, the second layer disposed between the first layer and the third layer,

the first layer defining a first port therethrough and at least one of the first and the third layers defining a second port therethrough to permit fluid flow from the first port to the second port through a flow area defined by the second layer,

the second layer defines a displaceable structure and at least one actuator disposed relative to a first end of the displaceable structure to move the displaceable structure in a plane parallel to the second layer, the displaceable structure movable to place a second end portion thereof at a position between an open and a closed position relative to one of the first and the second ports; and

a fourth layer, the third layer disposed between the second and the fourth layers, wherein the first layer, the second layer and the third layer define a channel therethrough, the channel being enclosed in part by the fourth layer and having an opening in each of the first and the third layers for delivery of fluid from the first layer opening to the third layer opening and into the flow area, the third layer opening being substantially coaxially disposed relative to the first port of the first layer.